The Southeast Bering Sea Ecosystem: Implications for Marine Resource Management (Final Report: Southeast Bering Sea Carrying Capacity)

S. Allen Macklin and George L. Hunt, Jr. (Editors)

Executive Summary

Background

Southeast Bering Sea Carrying Capacity (SEBSCC, 1996–2002) was a NOAA Coastal Ocean Program project that investigated the marine ecosystem of the southeastern Bering Sea. SEBSCC was co-managed by the University of Alaska Fairbanks, NOAA Alaska Fisheries Science Center, and NOAA Pacific Marine Environmental Laboratory. Project goals were to understand the changing physical environment and its relationship to the biota of the region, to relate that understanding to natural variations in year-class strength of walleye pollock (*Theragra chalcogramma*), and to improve the flow of ecosystem information to fishery managers.

In addition to SEBSCC, the Inner Front study (1997–2000), supported by the National Science Foundation (Prolonged Production and Trophic Transfer to Predators: Processes at the Inner Front of the S.E. Bering Sea), was active in the southeastern Bering Sea from 1997 to 1999. The SEBSCC and Inner Front studies were complementary. SEBSCC focused on the middle and outer shelf. Inner Front worked the middle and inner shelf. Collaboration between investigators in the two programs was strong, and the joint results yielded a substantially increased understanding of the regional ecosystem.

SEBSCC focused on four central scientific issues: (1) How does climate variability influence the marine ecosystem of the Bering Sea? (2) What determines the timing, amount, and fate of primary and secondary production? (3) How do oceanographic conditions on the shelf influence distributions of fish and other species? (4) What limits the growth of fish populations on the eastern Bering Sea shelf? Underlying these broad questions was a narrower focus on walleye pollock, particularly a desire to understand ecological factors that affect year-class strength and the ability to predict the potential of a year class at the earliest possible time. The Inner Front program focused on the role of the structural front between the well-mixed waters of the coastal domain and the two-layer system of the middle domain. Of special interest was the potential for prolonged post-spring-bloom production at the front and its role in supporting upper trophic level organisms such as juvenile pollock and seabirds. Of concern to both programs was the role of interannual and longer-term variability in marine climates and their effects on the function of sub-arctic marine ecosystems and their ability to support upper trophic level organisms.

The eastern Bering Sea contains an Oceanic Regime that occupies the basin and a Shelf Regime that occupies the eastern shelf. The Oceanic Regime of the eastern basin is influenced by Alaska Stream water that enters the Bering Sea through Amchitka and Amukta passes in the Aleutian Islands, and turns northeastward to form the Aleutian North Slope Current. This current is the major source of water for the Bering Slope Current that sometimes follows the depth contours of the eastern shelf northwestward with a regular flow, and sometimes degenerates into an ill-defined, variable flow characterized by numerous eddies and meanders. These eddies are potentially important as habitat for larval and juvenile pollock, and can carry these fish, as well as nutrient salts, from the Oceanic Domain into the Outer Shelf Domain.

The broad continental shelf (up to 500 km wide) of the southeastern Bering Sea is differentiated into three bathymetrically fixed domains: the Coastal Domain that extends from the shore to about the 50-m isobath, the Middle Shelf Domain, between the 50-m and 100-m isobaths, and the Outer Shelf Domain that ranges from 100 m to 200 m in depth. The domains are separated by fronts or transition zones, with the narrow (5 to 30 km) Inner Front or Structural Front between the Coastal Domain and the Middle Shelf Domain, the wide (>50 km) middle transition zone between the Middle Shelf Domain and the Outer Shelf Domain, and the Outer Front between the Outer Shelf Domain and the waters of the slope.

Results

Many of the important advances in our understanding of the coupling of regional atmospheric processes, physical processes in the Bering Sea, and biological responses to these forcing mechanisms have resulted from SEBSCC and Inner Front research. Among these advances in our knowledge are:

1. A new understanding of the importance of warm-season climate
2. An improved understanding of the functions of the Aleutian North Slope Current and the Bering Slope Current and their potential importance to fish
3. Documentation of eddies over the slope and along the outer shelf and their importance as habitats for fish and for the transport of small pollock onto the shelf
4. Development of a model that resolves eddies and suggests that the source of eddies in the southeastern Bering Sea basin is in the Bering Slope Current
5. Discovery of mean flows across the shelf, which, for short intervals in summer, can result in replenishment of salts and transport of oceanic zooplankton to the Inner Front
6. A clarification of the role of the timing of ice retreat for the timing and fate of the spring phytoplankton bloom

7. Understanding of the relative importance of winter and warm season conditions for determining the timing and strength of spring stratification and the potential for summer mixing across the pycnocline

8. An understanding of the temporal and spatial variability of the Inner Front and its role in nutrient fluxes from depth

9. A greater appreciation for the role of water temperature in the distribution of fish, especially pollock, the hatching time of pollock eggs, and the population dynamics of zooplankton

10. A greater appreciation for the role of episodic events in structuring the ecosystem

11. A new hypothesis concerning the role of wind-forced transport for the survival of juvenile walleye pollock

12. Evidence that the net annual primary production in the northern Bering Sea may be declining, whereas in the southeastern Bering Sea, increases in standing stocks of fish and non-crab benthic invertebrates do not suggest a decline in production

13. Commencement of research on the role of nanno- and microplankton, including coccolithophores, in the marine ecosystem of the southeastern Bering Sea

14. From re-examination of zooplankton time series, no evidence for a significant decline in zooplankton biomass within samples stratified by the domain in which they were collected

15. Immense increases in the biomass of large jellyfish and then a rapid decline to levels seen in the early 1980s

16. Observations of responses of crustacean zooplankton to variations in water temperature, including apparent shifts in the timing of breeding in shelf euphausiids, and the abundance of small shelf copepods

17. Determination that large cetaceans are now encountered more frequently in shelf waters than in the 1970s, and that substantial numbers are present over the shelf during summer

18. Progress in defining multiple hypotheses concerning the control of year-class strength in walleye pollock

19. Improved understanding of the foraging habits and diets of marine birds, northern fur seals, and Steller sea lions at the Pribilof Islands; the potential relationships between the abundance of adult pollock over the shelf and the reproductive success of black-legged kittiwakes at the Pribilof Islands

20. Evidence that sub-lethal food stress during the breeding season can lead to elevated levels of corticosteroids, and possibly elevated levels of post-breeding season mortality in seabirds

21. Development of a mechanistic explanation of how variations in climate could cause shifts in the mechanisms controlling walleye pollock populations (Oscillating Control Hypothesis)

Elements of these advances were used to develop indices for prediction of walleye pollock year-class strength. A conceptual switch model that relates survival of pollock from one developmental stage to the next is a function of environmental parameters, such as climate, sea ice, and timing of prey production. The Oscillating Control Hypothesis is an important climate element of the conceptual model. The following indices are some that were developed by SEBSCC as potentially useful for predicting pollock abundance based on elements of the conceptual model.

1. An index of wind turbulence versus larval feeding success
2. An index of variations in net short-wave radiation
3. A new index of sea ice that led to insight regarding changes in timing of spring in the region
4. Indices related to thermal conditions developed from the compilation of water temperature data taken during annual trawl surveys
5. An index developed from simulations by the Northeastern Pacific Regional Ocean Model System (NEPROMS) that combines early-life-history transport and predation by adult pollock
6. An index from autumn age-0 pollock abundance that may be an acceptable early predictor for pollock year-class strength

An examination of a large set of biological and physical indices showed that potential relationships could change sign with regime shifts, providing a clear warning that a simple model does not exist.

SEBSCC also addressed the importance of age-0 pollock in the Pribilof Island region as possible indicators of future eastern Bering Sea pollock recruitment, and discussed relationships of age-0 pollock to their prey and predators. To this end, the Pribilof Island region was considered to include an area extending along the shelf and shelf-break 100 nm from the center of the islands. This determination was based on ecological efficiency predicted by the energetic/trophic-web-based ECOPATH model. According to its prediction, the largest percentage of the energetic demands of regional biota was met by food sources within that boundary.

Age-0 pollock abundance near the Pribilof Islands was generally higher than in the surrounding area, and was about the same as abundance in the Inner Front region. Drogued buoy trajectories suggest that most pollock found near the Pribilofs during summer likely come from spawning areas near Unimak Pass. Some may be spawned near Bogoslof Island or even closer to the Pribilofs.

There may be an interaction among the spatial distribution of adult pollock (that appears to have two modes over the years: a northwest and southeast mode), the relative importance of different pollock spawning areas and the summer wind patterns that can influence changes in the distribution of age-0 pollock over the summer. To whit, the abundance of age-0 pollock near the Pribilof Islands may change drastically throughout the summer.

It is difficult to establish a relationship between bird and mammal diets and abundance of age-0 pollock near the Pribilof Islands. No such relationships were found for murres or kittiwakes. Percent occurrence of age-0 pollock otoliths in fur seal scat was high throughout most summers, which suggests that large year classes cannot be distinguished from moderate-sized year classes by scat samples. However, small pollock year classes may be distinguishable using scat data.

The vast quantity of information collected during SEBSCC and Inner Front has led to new understanding and hypotheses of how the southeastern Bering Sea ecosystem functions. This information is providing input to the National Marine Fisheries Service's stock assessment of juvenile pollock. At present, the pathway to providing input is through a grass-roots approach; the integrative research method employed during SEBSCC included fisheries scientists at the Alaska Fisheries Science Center whose tasks are directed toward status of stocks. Some of these scientists were SEBSCC Principal Investigators and/or members of SEBSCC Working Groups. They were the ones who helped to develop indices of potential survival of early life histories of pollock and a formal technique to use such indices in stock assessment models. The quantitative use of annual metrics of the physical and biological environment is the next logical step in the progression toward improved forecasts of age-1 recruitment. As the management of fisheries matures toward an ecosystem-based approach, the integrated biophysical knowledge attained by fisheries scientists during SEBSCC and Inner Front will prove to be an invaluable foundation.

Future Research

Although a great deal of progress in understanding the forcing mechanisms and the ecosystem responses of the southeastern Bering Sea has been made since the early 1990s, there are still many unanswered questions that demand attention if we are to provide good stewardship for the resources of the Bering Sea shelf. Answers to these questions go beyond academic value; we need to understand the processes and mechanisms that determine how changes in global climate and the associated physical forcing affect the flow of energy to upper trophic level organisms including commercially valuable fish and shellfish, marine mammals, and seabirds. Below are listed a number of questions that require attention.

1. How do atmospheric forcing mechanisms influence the distribution and transport of salts, heat, nutrients, and organic matter in the eastern Bering Sea?

2. How is the timing and magnitude of cross-shelf flux controlled?

3. How do different patterns in the formation, thickness, extent, and melt-back of sea ice influence the ecosystems of the eastern Bering Sea shelf?

4. What controls the amount and fate of primary production?

5. What controls the biomass and productivity of upper trophic level organisms?

6. How can we translate information about Bering Sea ecosystems into products useful to those who are managing the fisheries of the eastern Bering Sea?

The following are logical next steps in the development and refinement of indices. The first steps deal with indices for estimating recruitment of age-1 pollock. The last is an index that may provide guidance regarding interpretation of the annual stock assessment from trawl results.

1. Continue comparisons with other model simulations and observations to provide verification of the Bering Sea model (NEPROMS).

2. Develop a wind index of nutrient supply to the shelf from Bering Canyon.

3. Develop a user interface and/or other techniques so the NEPROMS is more accessible as a tool.

4. Examine various indices versus occurrence of northwest and southeast centers of the adult pollock population.

5. Extract an index of zooplankton abundance from ECOSYM.

6. Develop a history of the time/space occurrence of the pollock-roe fishery to help define time/space limits for pollock eggs as initial points for trajectory simulations.

7. Develop a similar product for pollock spawning that occurs near Bogoslof Island.

8. Use temperature observations from annual trawl surveys to develop an index of the presence of the cold pool and the locations of the inner and middle fronts (i.e., the boundaries of the middle shelf domain) in given years.

9. Use temperature observations to create annual distributions of temperature that, in turn, can be used to simulate zooplankton production.

10. Examine the influence of changes in the physical environment (e.g., water temperature, location of fronts) on preferred habitat for pollock, and how variations in these features affect estimates from trawl results.

With the results of SEBSCC and the Inner Front Study, the stage is set for future research programs to increase understanding of regional processes, their coupling to larger-scale phenomena, and the impacts that changes to this ecosystem will have on our society, and vice versa. Several programs and projects on the immediate horizon will be the first to contribute. Programs such as the Bering Sea Ecosystem Study (BEST) (`http://www.arcus.org/bering/`) and the Study of Environmental Arctic Change (SEARCH) (`http://psc.apl.washington.edu/search/`) are developing research plans for the Bering Sea and the waters to the north, and they will be supported by ongoing efforts from the North Pacific Research Board, Fisheries-Oceanography Coordinated Investigations (FOCI), the National Marine Fisheries Service, Alaska Ocean Observing System, North Pacific Anadromous Fish Commission, and others.